FINAL REPORT

STUDY 8: REVIEW OF METHODS TO MONITOR CHANNEL CAPACITY OF THE OKANOGAN RIVER DOWNSTREAM OF OSOYOOS LAKE – PART 1

Prepared for:

International Joint Commission
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Project 5501-002.01

January 2010

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January 31, 2010

Reference: 5501-002.001

Mr. Tom McAuley
International Joint Commission
234 Laurier Avenue West
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Dear Mr. McAuley:

Re: International Joint Commission (IJC) Study 8: Review of methods to monitor channel capacity of the Okanogan River between outlet of Osoyoos Lake and Zosel Dam – Part 1

Summit Environmental Consultants Ltd. is pleased to submit this final report on the above-noted study. This report is the major deliverable for Part 1 of the two-part study.

We trust this meets your requirements for Part 1 of Study 8. Upon your direction we will proceed with Part 2 of the study.

Yours truly,

Signature on original

Brian Guy, Ph.D., P.Geo., P.H.
Project Manager

ACKNOWLEDGEMENTS

This study was completed by a team led by Brian Guy, Ph.D., P.Geo., P.H., of Summit Environmental Consultants Ltd. (Summit). Lars Uunila, M.Sc., P.Geo., P.H., CPESC, of Polar Geoscience Ltd. was the technical leader. Additional contributions were made by Drew Lejbak, M.Sc., of Summit, and by Michael MacLatchy, Ph.D., P.Eng., of Associated Engineering. Ray Newkirk and his colleagues at the Washington State Department of Ecology (WSDOE) provided information and advice that greatly facilitated completion of the analyses.

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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

In 1946, the International Joint Commission (IJC) approved the construction of the Zosel Dam, subject to a number of conditions. One of the conditions was that the dam have sufficient capacity to maintain water levels at a gauge not more than 300 feet (91.4 m) upstream of the dam at or below 911.0 ft (277.7 m) above sea level, while discharging 2,500 ft^3/s (70.8 m^3/s) . However, in 1982 the Zosel Dam was in a deteriorated condition and unable to meet that requirement.

To mitigate those issues, the 1982 Orders approved the construction of a new dam (i.e. the existing one). In 1985, the IJC amended the Orders to move the dam downstream, avoiding the need to relocate Tonasket Creek and preserving associated wetlands. According to the IJC, the new dam was not to create flood levels greater than would have occurred if the original Zosel Dam had remained in place and been maintained and operated in accordance with the 1946 Order of Approval.

However, the IJC was aware that blockages formed occasionally in the Okanogan River between Osoyoos Lake and the Zosel Dam (Thayer, 1939; Webb and Veatch, 1946). These blockages reduced the river's capacity, and if the capacity of the river was allowed to be reduced, the control point for lake water levels would be shifted from the dam to the river, and therefore the ability to regulate storage would be lost and the risk of flooding along Osoyoos Lake would increase. To address this issue, Condition 4 of the Supplementary Order of Approval of 1985 requires the following:

> *"The Applicant (Washington State Department of Ecology) shall take all measures necessary to ensure that the flow capacity of the Okanogan River, upstream and downstream from the control structure (i.e. Zosel Dam), enables the control structure to pass at least 2,500 cubic feet per second when the elevation of Osoyoos Lake is 913.0 feet USCGS and there is no appreciable backwater effect from the Similkameen River."*

After the construction of the new Zosel Dam in April 1987, a number of measures were taken to improve the flow capacity of the Okanogan River. These measures were completed by

February 1988 (Washington State Department of Ecology (WSDOE), 1990) and included dredging and/or excavation of the channel at the following locations (roughly delineated in Figure 1 by dashed lines):

- near the outlet of Osoyoos Lake;
- near the mouth of Tonasket Creek;
- between Tonasket Creek and the new dam; and
- between the new dam and the Burlington Northern Railway crossing.

In order to minimize bank erosion at Osoyoos Lake State Park near the outlet of Osoyoos Lake, a sheet pile wall was also installed along 600 ft (183 m) of the right (west) bank of the river (WSDOE, 1990).

1.2 PROJECT OBJECTIVES

The IJC Orders of Approval are due to be renewed in 2013 and, prior to that time, assurance is required that the present monitoring methods will indeed detect reductions in the capacity to convey flows in the Okanogan River, and that the present method is the most practical, cost effective and risk averse method for measuring channel capacity.

The principal objectives of this two-part investigation are to:

- Part 1: Assess the efficacy of the present river monitoring program, place it in context with other possible options currently available, and discuss whether changes to the present monitoring program are warranted; and
- Part 2: If changes to the present system are warranted, conduct further investigation to support detailed recommendations for a future monitoring program to be included in the reissued Orders in 2013.

This memo highlights the findings of Part 1 and summarizes the methods used, describes the current river monitoring program, discusses its advantages and disadvantages, outlines optional monitoring methods, and provides recommendations for subsequent work in Part 2.

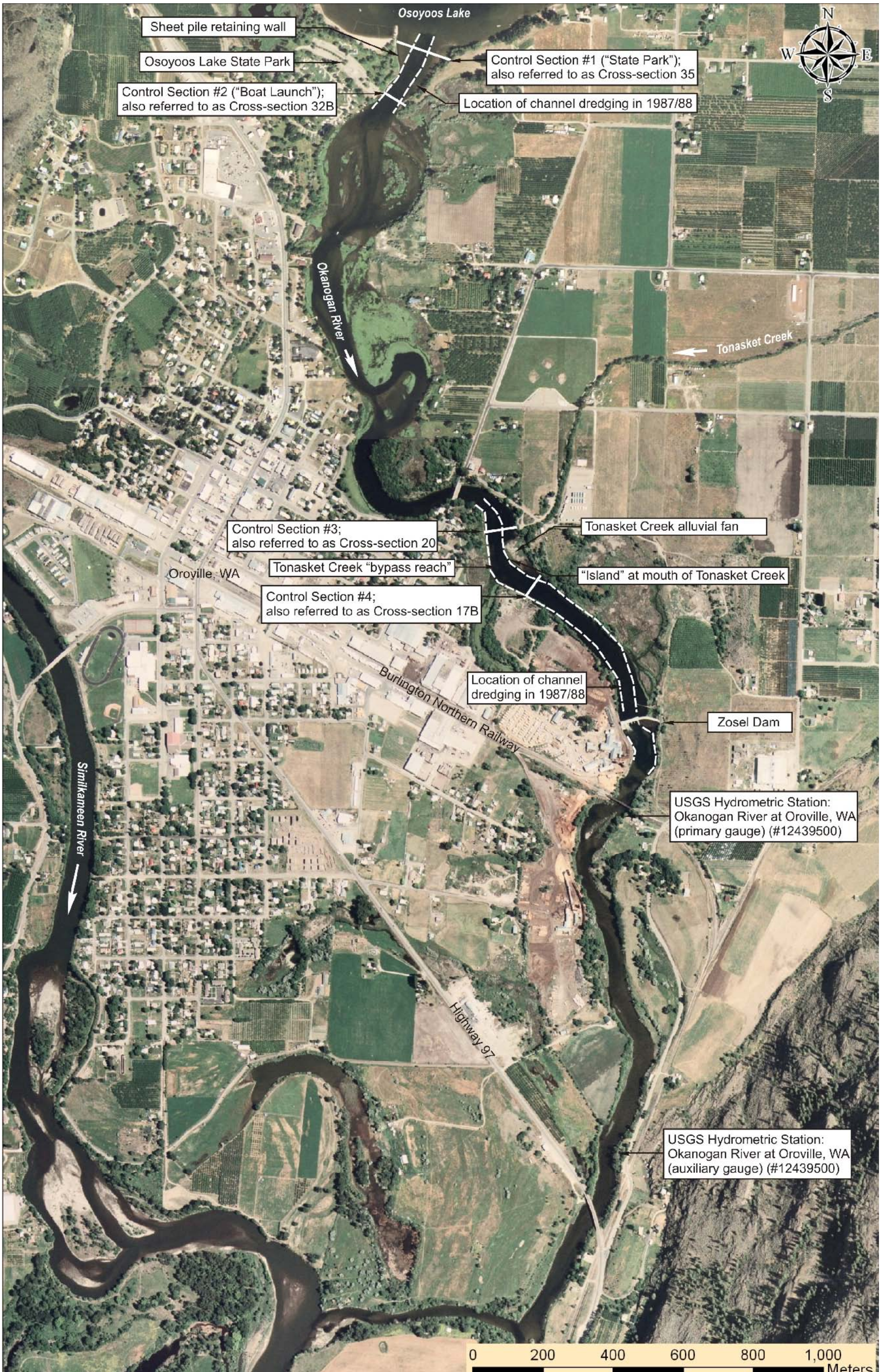

Figure 1. Orthophoto map of the Okanogan River between Osoyoos Lake and Similkameen River confluence. Dashed lines indicate the approximate locations of channel excavation and dredging completed in 1988.

2.0 METHODS

Part 1 of this investigation involved the following activities:

1. A start-up meeting in Oroville, WA was held on June 25, 2009 to discuss the project and background information. Attendees of the meeting included:
    1. Brian Guy and Drew Lejbak of Summit Environmental Consultants Ltd.;
    2. Lars Uunila of Polar Geoscience Ltd.;
    3. Kathleen Porter of Sequoia Mediation;
    4. Daniel Millar, Kirk Johnstone, and Robert Kimbrough of the International Osoyoos Lake Board of Control ; and
    5. Ray Newkirk of Washington State Department of Ecology.

2. Following the start-up meeting, a field visit was made to Zosel Dam, Okanogan River (at selected locations including the outlet of Osoyoos Lake, mouth of Tonasket Creek, USGS hydrometric station *Okanogan River at Oroville,* and near the Similkameen River confluence), and Osoyoos Lake at the USGS hydrometric station.

3. Compilation of hydrometric data from USGS hydrometric stations at Okanogan River at Oroville WA (#12439500) and Osoyoos Lake near Oroville, WA (#12439000).

4. Review of background documents relevant to the investigation, including the following:
    1. Acres (1986);
    2. Glenfir Resources (2006);
    3. International Osoyoos Lake Board of Control (IOLBC) (1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999a, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007);
    4. Washington State Department of Ecology (1990, 1992, 2007);
    5. Thayer (1939); and
    6. Webb and Veatch (1946).

5. Analysis of the hydrometric records collected by the USGS since completion of the present Zosel Dam and associated channel improvements in early 1988. This analysis was performed to confirm that the Okanogan River has the capacity to convey 2,500 ft^3/s (70.8 m^3/s) while Osoyoos Lake is at a level of 913.0 ft (USCGS) or lower (i.e. Condition 3 of the Supplemental Order of Approval).

6. With the assistance of the Washington State Department of Ecology (WSDOE), survey data of Okanogan River cross-sections were compiled and analyzed to confirm any cross-sectional changes that have occurred over the last two decades. Four (4) "control sections" were established for these purposes, including:
    1. Control Section "Okanogan River at Osoyoos Lake";
    2. Control Section "Okanogan River at Boat Launch";
    3. Control Section "Okanogan River above Tonasket Creek"; and
    4. Control Section "Okanogan River below Tonasket Creek".

7. A review and evaluation of the current and optional hydraulic models was performed by members of the study team from Associated Engineering. This review was performed by the following two water resource engineers:
    - Michael MacLatchy, Ph.D., P.Eng., Senior Water Resources Engineer; and
    - John van der Eerden, M.Eng., P.Eng., Manager Water Resources Group.

8. With the assistance of the WSDOE, the most recent HEC-RAS hydraulic model output was compiled. This data, which included model runs under two (2) discharges (2,500 ft^3/s and 2,680 ft^3/s) were reviewed by members of the study team from Associated Engineering, to assess the reasonableness of the model parameters.

9. Telephone interviews were held with the following experienced individuals to solicit comment on the present river monitoring system and other monitoring methods available that may have merit:
    1. Ray Newkirk, P.E., Washington State Department of Ecology, Olympia, WA;

2. Guy Hoyle-Dobson, Washington State Department of Ecology, Olympia, WA;
3. Michael Church, Ph.D., Department of Geography, University of British Columbia;
4. Brett Eaton, Ph.D., Department of Geography, University of British Columbia;
5. Robert Millar, Ph.D., P.Eng., P.Geo., Department of Civil Engineering, University of British Columbia;
6. Chistopher Magirl, United States Geological Survey, Tacoma, WA;
7. Rudy Enns, Cansel, Vancouver, BC; and
8. Shawn Ternan, Hoskin Scientific Limited, Vancouver, BC.

10. A synthesis of the current and optional monitoring system components was made to judge its cost, requirements, practicality, accuracy, and level of risk that reductions in channel capacity could go unnoticed.

11. Preparation of this report.

3.0 CURRENT MONITORING SYSTEM

3.1 OVERVIEW

Following channel improvements in 1988 (described above), the WSDOE established four (4) "control" cross-sections. These included two (2) cross-sections near the outlet of Osoyoos Lake, and two (2) near the mouth of Tonasket Creek (Figure 1) (Newkirk, pers. comm., 2009). Historically, these areas have been the most likely locations to experience sedimentation and loss of flow capacity (Thayer, 1939; Webb and Veatch, 1946).

At the outlet of Osoyoos Lake, shoreline erosion and long-shore drift of sediments has some potential to introduce sediment to the Okanogan River near the outlet. Hydraulic conditions (i.e., most notably stream gradient as regulated by Zosel Dam and the level of Osoyoos Lake) dictate whether sediments that deposit near the outlet are scoured or not by streamflows and transported downstream. Observations and surveys over the last two decades have shown that sedimentation has not been significant in the area dredged (Figure 1) (Newkirk, pers. comm., 2009). One likely reason for this is the construction of the sheet pile retaining wall along a portion of Osoyoos Lake State Park (Figure 2). This has reduced the volume of sediment that can locally be redistributed by waves and currents. Nevertheless, there are lengths of sandy shoreline near the lake outlet that are vulnerable to erosion. Under the action of waves and currents, some of this sediment could be transported to the area near the outlet of the lake and downstream.

Figure 2. Okanogan River at the outlet of Osoyoos Lake. Date June 25, 2009. Osoyoos Lake daily water level 912.3 ft.

Tonasket Creek is a small high energy intermittently flowing creek that has a history of transporting sediment derived from low-lying terraces and foothills on the east side of the

Okanogan Valley. Tonasket Creek normally flows during spring freshet and in response to rainstorms, but is dry for the remainder of the year. Rainstorms and particularly intense convective thunderstorms, although relatively short in duration, tend to be the main cause of streamflows capable transporting bed material in Tonasket Creek and ultimately sediment deposition in Okanogan River. Near the mouth, Tonasket Creek has formed an alluvial fan into the Okanogan River (Figures 1 and 3). The distal (i.e. lower) portion of this fan forms a vegetated island, which at low river levels is connected to the left (east) bank (Figure 3). In some years (e.g. 1918, 1939), sediment transported by Tonasket Creek has been reported to "completely block the river" (Thayer, 1939). Given there are no measures on Tonasket Creek to control sediment transported to the Okanogan River, Tonasket Creek continues to pose a risk of delivering sediment to the Okanogan River.

Figure 3. View from east to west of the Tonasket Creek fan. Okanogan River flows from right to left. Date: June 25, 2009. Okanogan River daily discharge 177 ft^3/s (regulated by Zosel Dam located downstream).

To minimize this risk, channel improvements in 1988 included the excavation/dredging of a "by-pass" channel along the right (west) bank of the river. An area along the left (east bank) of the river directly in front of the mouth of Tonasket Creek and east of the small "island" was intended to provide an area for sediment deposition and storage. If or when the sediment volume from Tonasket Creek exceeds the capacity of this storage area and if sediment were to migrate downstream a reduction in channel capacity is possible.

In 1998, the WSDOE and the International Osoyoos Lake Board of Control (IOLBC) agreed that annual hydrometric records of Okanogan River discharge and Osoyoos Lake water levels would be used as a primary means to verify the channel capacity of the Okanogan River. This agreement is documented in an October 7, 1999 letter from IOLBC to WSDOE (IOLBC, 1999b, Appendix A). However, if five (5) consecutive years pass without discharges or lake levels sufficient to perform this verification, the four (4) control sections noted above would be resurveyed, and a 1-dimensional backwater hydraulic analysis (e.g., HEC-RAS) would be performed to assess channel capacity prior to the sixth year. These four (4) control sections would also be re-surveyed every 10 years and would form the basis of a revised hydraulic analysis regardless of the hydrologic conditions observed. Furthermore, according to IOLBC (1999b), the IOLBC reserves the right to request a resurvey at any time if there is reason to believe that a change has taken place to decrease the conveyance of the river.

3.2 TIMELINE OF MONITORING ACTIVITIES

Table 1 summarizes the monitoring activities performed under the direction of the WSDOE since 1988. Information was compiled from WSDOE files supplied by Mr. Ray Newkirk and other quoted references.

Table 1. Summary of monitoring activities within the Okanogan River channel performed under the direction of the WSDOE from 1988 to 2008.

Year	Activity
1988	Channel improvements designed to permit the design flow were completed in February 1988. Control sections were surveyed on February 23, 1988.
1989	No survey was conducted. As shown in Table 2, the hydrometric data did not permit confirmation of channel capacity, therefore sufficient channel capacity was assumed based on the 1988 survey.
1990	Hydrometric records confirmed channel capacity (IOLBC, 1990); Cross-sections were surveyed by Department of Ecology and U.S. Corps of Engineers in May 1990 (WSDOE, 1990). Control sections were surveyed on August 16-17, 1990.
1991	The hydrometric records for 1991 confirmed channel capacity (IOLBC, 1991). Regardless, the control sections were surveyed on October 1-2, 1991.
1992	Control sections were surveyed on August 27-28, 1992. IOLBC (1992) indicates that on October 16, 1992 the Department of Ecology analyzed the control sections and confirmed channel capacity to be 2,500 ft^3/s.
1993	Control sections were surveyed on October 12-13, 1993.
1994	Control sections were surveyed on August 30-31, 1994. IOLBC (1994) indicates that the Department of Ecology ran the HEC model and confirmed channel capacity.
1995	Control sections were surveyed on October 5, 1995. IOLBC (1995) indicates that DOE ran the HEC model and confirmed channel capacity.
1996	The hydrometric records for 1996 confirm channel capacity (IOLBC 1996). Nevertheless, the control sections were surveyed on September 25-26, 1996.
1997	The hydrometric records for 1997 confirm channel capacity (IOLBC, 1997).
1998	The hydrometric records for 1998 confirm channel capacity (IOLBC, 1998).
1999	The hydrometric records for 1999 confirm channel capacity (IOLBC, 1999a).
2000	The channel capacity was assumed sufficient based on 1997, 1998, 1999 data.
2001	The channel capacity was assumed sufficient based on 1997, 1998, 1999 data.
2002	The hydrometric records for 2002 confirm channel capacity (IOLBC, 2002).
2003	The channel capacity was assumed sufficient based on 2002 data.
2004	The channel capacity was assumed sufficient based on 2002 data.
2005	The channel capacity was assumed sufficient based on 2002 data.
2006	The hydrometric records for 2006 confirm channel capacity (IOLBC, 2006). The control sections were surveyed in October 2006 and HEC-RAS model run in January 2007. As a result of the modeling, sufficient channel capacity was reported.
2007	The channel capacity was assumed sufficient based on 2006 data and survey/modeling.
2008	The channel capacity was assumed sufficient based on 2006 data and survey/modeling.
2009	The channel capacity was assumed sufficient based on 2006 data and survey/modeling.

3.3 REVIEW OF HYDROMETRIC RECORDS

Since 1998, a review of the hydrometric records has been a principal means of confirming that the channel capacity of the Okanogan River meets Condition 3 of the Supplementary Order of Approval of 1985. This review specifically involves confirming that the Okanogan River at Oroville, WA (USGS Station #12439500) conveys a minimum of 2,500 ft^3/s (70.8 m^3/s) when the lake level in Osoyoos Lake near Oroville, WA (USGS hydrometric station #12439000) is at 913.0 ft (USCGS) or lower.

The primary advantage of this method is that it **provides a direct measure** of the channel capacity and utilizes information already collected by the USGS according to federal standards. A relatively modest amount of analysis is required by staff of the WSDOE to confirm if channel capacity is sufficient. The disadvantage of this method is that channel capacity can only be confirmed in years when flows in the Okanogan River are of sufficient magnitude (i.e. greater than or equal to 2,500 ft^3/s (70.8 m^3/s). Between 1988 and 2009, Okanogan River flows were sufficient to assess channel capacity in only 8 of 22 years (36% of the years) (Table 2). As a result, this method alone can not provide assurance of channel capacity in each year.

Also, since the examination of hydrometric records is generally completed after (or possibly during[1]) a high flow event, if any channel capacity reduction were identified, it would typically be too late to initiate channel works to mitigate impacts for that period of high flow and water levels. Furthermore, the examination of hydrometric records cannot identify whether sedimentation that might occur during the latter stages of a high flow event has reduced channel capacity until the next sufficiently high flow event occurs on the Okanogan River.

[1] Real-time "provisional" data is available at the two principal hydrometric stations.

Table 2. Years when the hydrometric record demonstrated conveyance capacity of the Okanogan River as per Condition 3 of the Supplementary Order of Approval (1985).

Year	Does the hydrometric record demonstrate conveyance capacity of the Okanogan River as per Condition 3 of the 1985 Order?		Year	Does the hydrometric record demonstrate conveyance capacity of the Okanogan River as per Condition 3 of the 1985 Order?	
	Yes	No		Yes	No
1988		✓	2000		✓
1989		✓	2001		✓
1990	✓		2002	✓	
1991	✓		2003		✓
1992		✓	2004		✓
1993		✓	2005		✓
1994		✓	2006	✓	
1995		✓	2007		✓
1996	✓		2007		✓
1997	✓		2008		✓
1998	✓		2008		✓
1999	✓		2009		✓

3.4 CHANNEL SURVEYS

As noted above, channel surveys and backwater hydraulic analyses are to be performed every 10 years or if 5 years pass without sufficiently high flows to confirm channel capacity using the hydrometric record.

To facilitate hydraulic modeling, the WSDOE first established a suite of detailed cross-sections on the Okanogan River between the outlet of Osoyoos Lake and Zosel Dam in September 1986 (Acres, 1986), prior to dam construction and channel dredging. Four (4) of the cross-sections in the key areas that were dredged became "control sections" for monitoring and hydraulic modeling purposes (Figure 1). These four (4) control sections are the only ones that are re-surveyed as necessary. According to Newkirk (2009), control sections were surveyed in the following years:

- 1988;
- 1990;
- 1991;
- 1992;
- 1993;
- 1994;

- 1995;
- 1996; and
- 2006

Each of the control sections is surveyed using a boat attached to a ¼ inch diameter tag line across the river between established monuments. Three (3) technicians perform the survey: one operates a level on shore, one holds a survey rod from the boat, and one operates the boat. The survey interval is not fixed but is field-determined and intended to collect breaks-in-slope along the bed of the river. This method relies on basic and proven surveying methods and equipment and is relatively straightforward and can be completed usually in 1-2 days (Newkirk, pers. comm., 2009). Some uncertainty in the measurements likely results from soft and/or heterogeneous bed conditions, chosen survey intensity on any given date, and/or operator error, which is minimized by having experienced personnel conduct the survey. This method of characterizing the channel (and bed elevation changes that suggest sedimentation or scour) however relies on the locations selected for the control sections. If for example some event leads to reductions in channel capacity at anywhere other than on the cross-sections near the lake outlet or mouth of Tonasket Creek, the present monitoring system is not likely to identify it.

Among the four control sections, the control section downstream of Tonasket Creek is the most likely section (if any) to reveal channel changes (Newkirk, pers. comm., 2009). The control section upstream of Tonasket Creek is located upstream of the Tonasket Creek fan and is not as likely to be impacted by sediment delivered by Tonasket Creek since a small "island" tends to direct any sediment deposition from the creek downstream along the left (east) bank of the Okanogan River where it eventually could affect Section #4 (Figure 1). However, if sediment is contained within the present area of the alluvial fan on the east side of the "island", the by-pass channel should have sufficient flow capacity, unless it too becomes subject to sedimentation from other sources upstream on the river. The likelihood of this happening however is relatively low.

Figures 4 to 7 show the control section surveys between 1988 and 2006. While there are some minor differences between most years at each control section stemming from possible measurement error and differences in survey intensity (i.e. the number of points surveyed along a given section), there appears to have been minimal change in the four (4) control sections over time, which is generally consistent with the findings of the WSDOE (Newkirk, pers. comm., 2009). The only exceptions to this appear to be the following:

- Apparent sedimentation of a depth of 2 ft that was noted at the control section "Okanogan River at Osoyoos Lake" between 1988 and 1990 along the east half of the section. However, based on our review of all other surveys at this location, this seems abnormally high and could be at least partially explained by measurement error in 1988;
- Apparent bed scour of a depth of 1 foot or less at "Okanogan River above Tonasket Creek" between 1996 and 2006; and
- Apparent sedimentation of a depth of approximately 1 foot at "Okanogan River below Tonasket Creek" between 1996 and 2006. If the survey data are assumed accurate, this observation could suggest that some of the sediment from Tonasket Creek may now be affecting the lowermost control section.

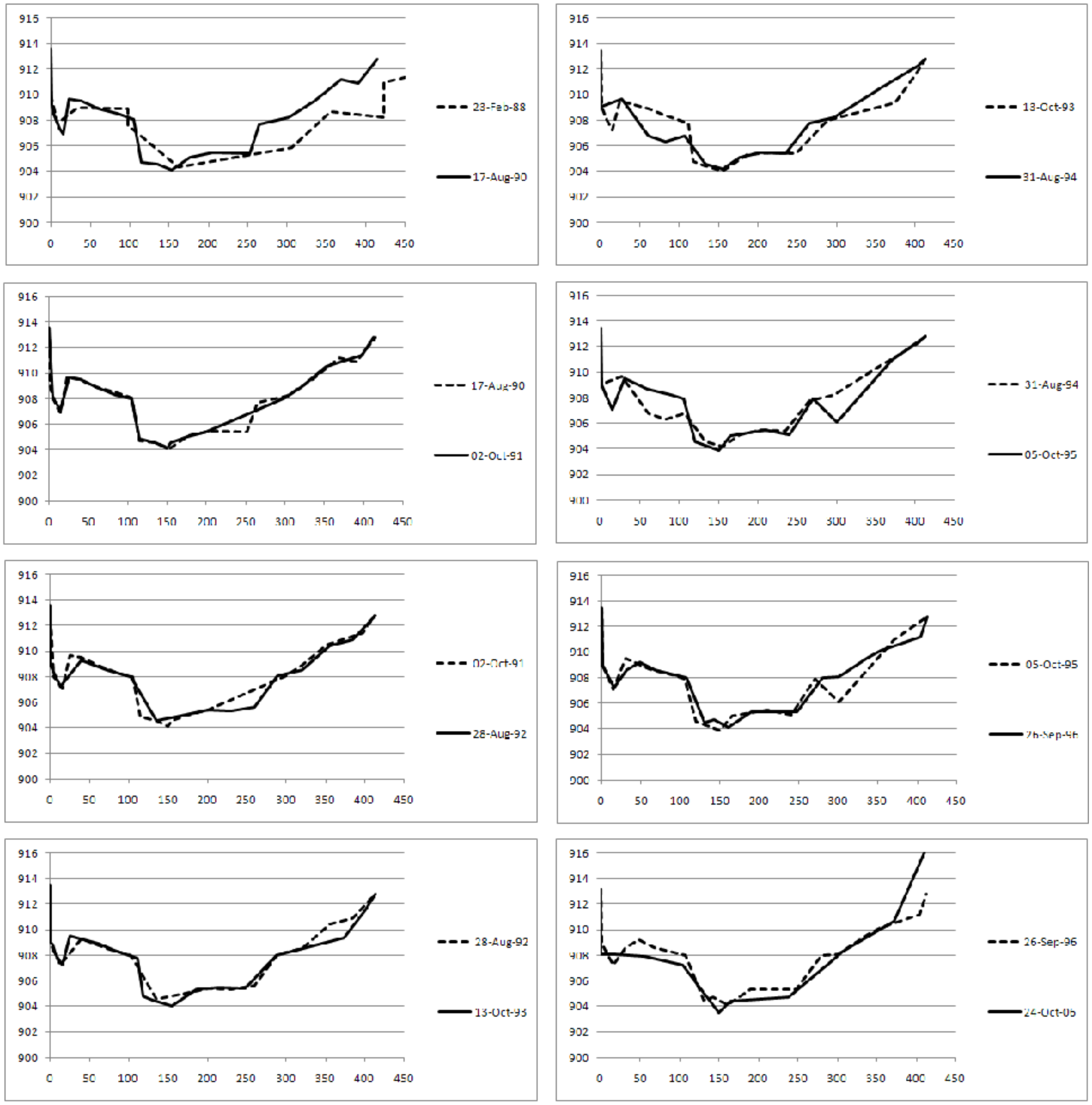

Figure 4. Survey of Control Section "Okanogan River at Osoyoos Lake (Near Cross-section 35)".

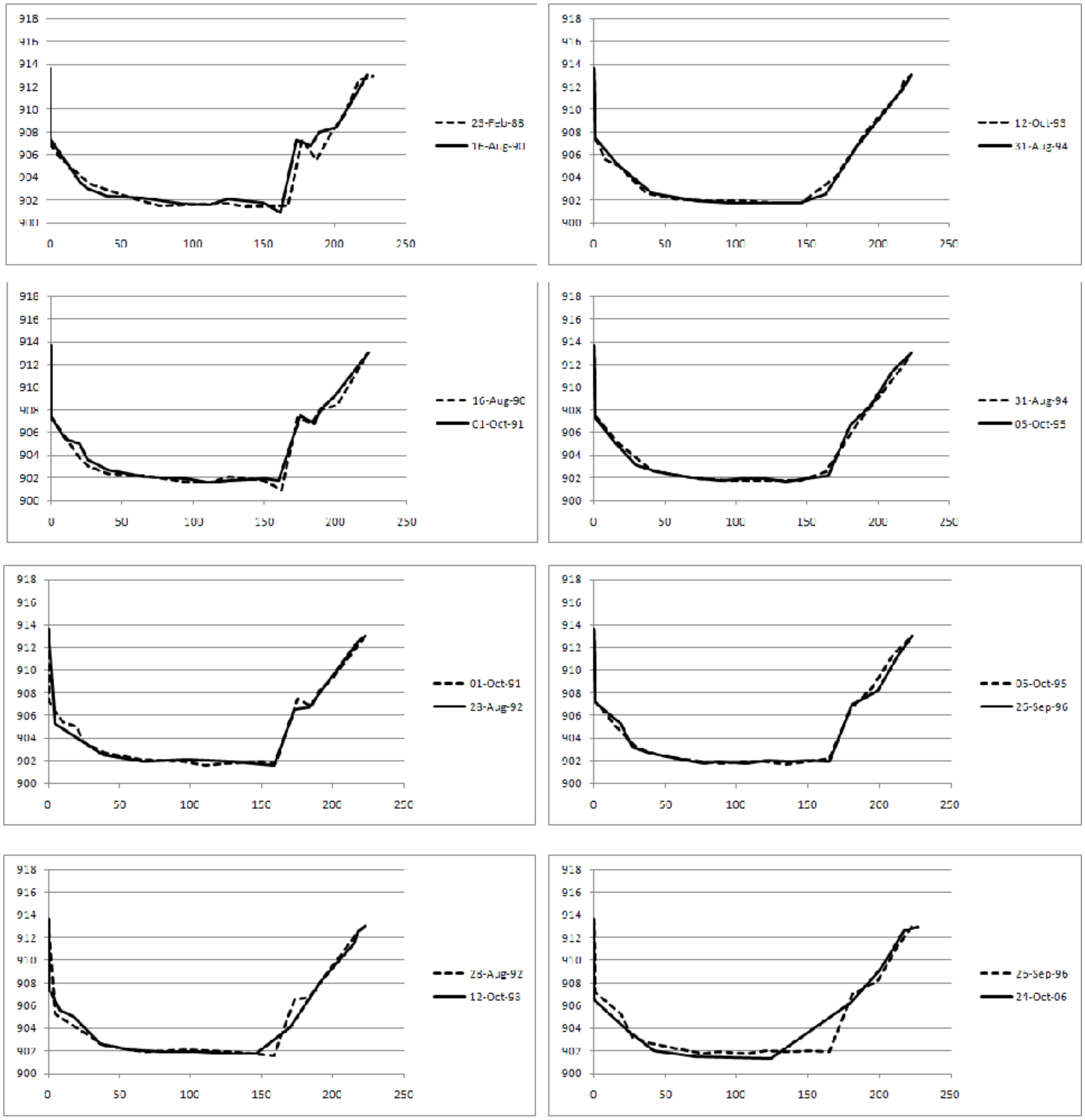

Figure 5. Survey of Control Section “Okanogan River at Boat Launch”.

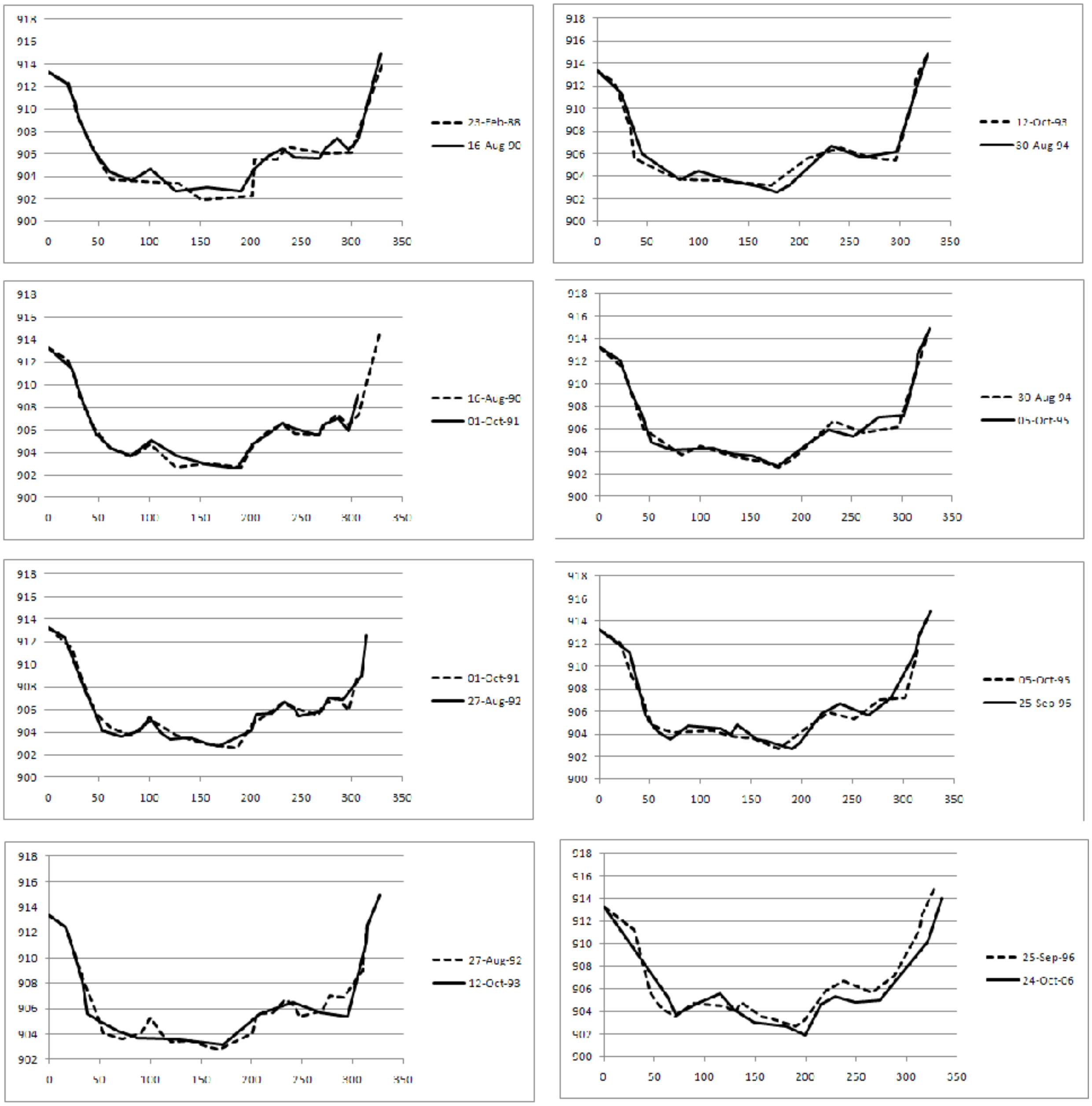

Figure 6. Surveys of Control Section "Okanogan River above Tonasket Creek".

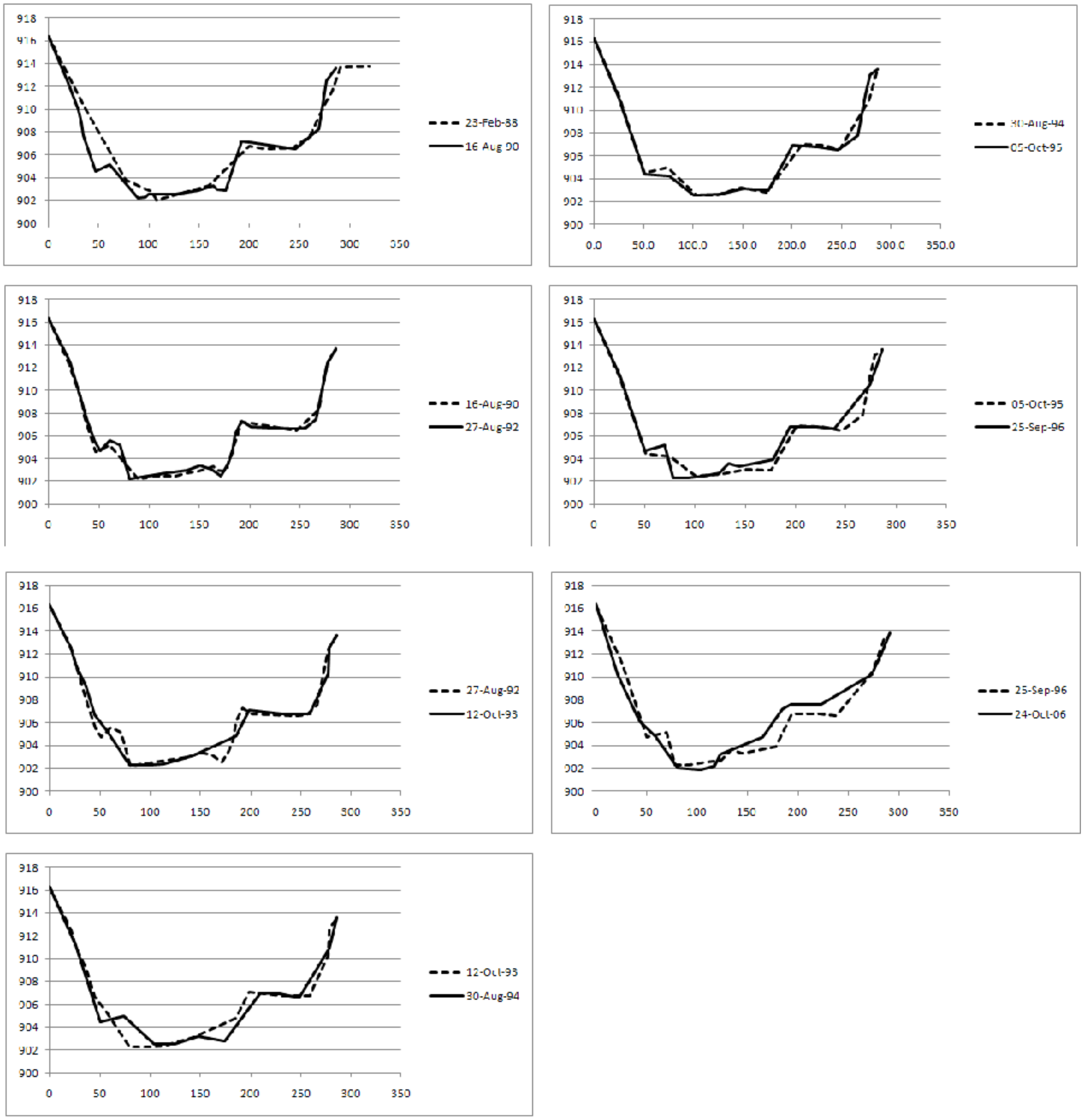

Figure 7. Survey of Control Section "Okanogan River below Tonasket Creek". Survey data for 1991 was unavailable.

3.5 HYDRAULIC MODELING

The WSDOE currently utilizes the U.S. Army Corp of Engineer's River Analysis System (HEC-RAS) software to perform one-dimensional steady flow river hydraulics calculations. The program models water flow through open channels and computes water surface profiles. It is based on the solution of the one-dimensional energy equation, whereby losses are evaluated by friction and contraction / expansion. HEC-RAS is an appropriate model to use to estimate hydraulic grade lines (HGLs) on the Okanogan River in order to identify flood levels and/or hydraulic capacity.

In order for HEC-RAS to reasonably estimate the HGL between Osoyoos Lake and Zosel Dam, two data sets are critical: **channel geometry** and **flow resistance**. In order to ensure ongoing reliability of the hydraulic model, calibration of the model to HGLs recorded during major flow events is desirable. Indirectly, a calibration will also indicate if conditions have varied from those incorporated in the initial model build.

3.5.1 Channel Geometry

According to the information available, the existing HEC-RAS model is built on the channel survey data collected prior to and immediately following the 1988 dredging program. Only the four control cross-section locations have been updated since that time; when coinciding flow and lake level conditions have not allowed for confirmation of the channel capacity during a period of 5 years or greater. The underlying assumption is that the four control cross-sections are in areas that will experience sedimentation first, and if no significant changes in geometry are identified by a particular survey, then the channel capacity is considered sufficient.

However, a period in excess of 20 years has passed since the base survey was completed. Given that time span, it would be prudent to conduct a re-survey of the entire channel to confirm whether channel geometry has varied to any significant degree. While sediment incursion from Osoyoos Lake should be minor, other factors could adversely impact the river channel. These include:

- Sediment inputs from lands adjacent to the river channel;
- Possible migration of fine sediment from the Tonasket Creek fan into the main channel; and
- Vegetation encroachment encouraging bar expansion.

Notably, several apparent areas of overbank or floodplain flow are visible in aerial photography (Figure 1). The fringes of these areas are potential zones for vegetation encroachment and sediment accumulation.

3.5.2 Flow Resistance

Hydraulic models such as HEC-RAS rely on an expression of the flow resistance in the modeled channel, in the form of Manning's "n". Manning's "n" estimates are based on experience and documented values for various channel types, channel substrate and vegetation. These documented values can vary over a wide range. Other factors that influence flow resistance are the presence of channel forms such as sand dunes and gravel bars. Vegetation encroachment over time will result in increased flow resistance and elevated HGLs.

Our review of the hydraulic model data provided indicates that the Manning's "n" values used by the WSDOE appear to be within ranges appropriate to the channel conditions apparent in aerial photography. However, the subject reach of the Okanogan River is relatively complex, exhibiting overbank flow areas, bends, vegetated bars and pools. Calibration of the hydraulic model with a HGL surveyed during a significant flow event would improve confidence in the model results. To our knowledge, a model calibration such as this has not previously been undertaken.

A flood event greater than 2,000 ft^3/s (57 m^3/s) would be preferred for calibration purposes. Lower flow rates will not adequately test the channel or make use of overbank flow areas that are subject to higher flow resistance due to vegetation. For this reason, calibration to a lesser event will likely not be representative of the conditions under which the stipulated capacity must be present.

4.0 OTHER MONITORING SYSTEMS

To provide some context for the present monitoring system, this section highlights other methods of monitoring channel capacity of the Okanogan River. This section includes evaluation matrices (Tables 3 and 4) that compare components of the present system with other potentially useful methods.

4.1 CHARACTERIZING THE CHANNEL GEOMETRY

At present, the Okanogan River between the outlet of Osoyoos Lake and Zosel Dam is characterized by four control sections located in two general areas. These sections are surveyed using level and rod at reasonably high accuracy and low cost. The rationale of surveying only the two general areas stems from a history of sedimentation at these locations. Nevertheless, there is some potential that sedimentation would not be detected at the four sections. For example, sediment that is transported to the outlet of Osoyoos Lake under the appropriate hydraulic conditions may be transported downstream beyond the surveyed area.

To increase the level of survey detail, a **total station survey** is possible. Using this method a technician with the prism could efficiently collect topographic information along selected (multiple) cross-sections within line of sight of the instrument. Topographic information can generally be collected in this manner more rapidly than rod and level. However equipment costs are higher and a surveyor with experience operating the instrument is necessary. Nevertheless, for the same amount of time the number of cross-sections surveyed or the level of detail per cross-section could be increased substantially, thereby reducing the risk of missing areas of sedimentation.

One alternative to surveying is to map the bathymetry of the river bed using a boat mounted **acoustic sounding instrument with GPS**. While the sounding equipment is relatively inexpensive, GPS technology ranges in price depending on the positional accuracy required. Mapping grade GPS has an accuracy of about 1 to 3 ft (0.30 to 0.91 m), while surveying grade GPS has an accuracy of 2 inches (5 cm) or better. Surveying grade GPS units would be required in this application. It requires two base receivers, but in Oroville, WA there is a fixed reference station that can be used as one of the base receivers for a relatively small fee. While the cost of equipment is high ($50,000-$100,000), there are alternatives, including:

- renting the necessary equipment for about $1,000-$2,000 per week (which includes a sounding device, 1 base receiver, software, and support);
- hiring a consultant specialized in hydrography; and
- coordinating with the USGS to contract equipment and/or personnel to perform the measurements.

One of the main benefits of this method is that detailed bathymetry can be obtained over considerable areas with less effort than required for conventional surveying. Furthermore, it would permit an evaluation of changes to the longitudinal profile of the river.

Remote sensing using **Airborne LiDAR Bathymetry (ALB)** is a technologically advanced technique that involves mounting a laser system with geo-referencing to an aircraft which flies over the area of interest. The system transmits a narrow beam of red and green light which reflect and penetrate water differently. When these beams are reflected back to the instrument, algorithms calculating the time lapses between the received echoes provides an indication of water depth. A good discussion of the technique is described in Hilldale et al. (2008), from which the following points were obtained. Compared to the boat mounted sounding and GPS, ALB can achieve greater point densities, more efficient data collection at a watershed scale, and more complete coverage. However, ALB currently has a mean vertical error between 0.33 – 0.89 ft (0.10 – 0.27 m) with a standard deviation of 0.39 – 1.0 ft (0.12 – 0.31 m) and cannot penetrate areas obscured by vegetation and steep slopes. Furthermore, the method is expensive, especially for short lengths of river, and can be dangerous to the human eye. ALB remains a topic of research and is not considered a viable method for monitoring the Okanogan River at this time.

Table 3. Evaluation matrix of the methods available to characterize channel geometry of the Okanogan River.

Monitoring Component	Equipment Cost (assuming purchase)	Operational Cost	Labour requirements	Practicality for this application	Accuracy	Risk of non-detection of capacity deficiency[1]
Level survey[2]	Low ($1000)	Low	Low	High	Moderate	Moderate
Total station survey	Moderate ($5,000-$10,000)	Low	Moderate	High	High	Low
Bathymetric mapping by sounding & GPS	High ($50,000-$100,000)	Moderate	Moderate	High	High	Low
Airborne LiDAR bathymetry	High ($250,000 - $500,000)	High	High	Low	Moderate	Moderate

1. Assumes use of well calibrated hydraulic model.
2. Method currently used.

4.2 HYDRAULIC MODELING

The HEC-RAS model, currently being used by the WSDOE, is widely employed for river hydraulics analysis in both the US and Canada, and is recognized as a reliable software package. However, other software packages are available that could be employed to estimate hydraulic grade lines (HGLs) and the capacity of the Okanogan River. These include two-dimensional and three-dimensional hydraulic models from both public domain and commercial sources. Some examples are listed below; the relative properties of each are presented in Table 4.

- **HEC-RAS** (US Army Corps of Engineers, Hydraulic Engineering Center): The model currently being used is a 1-dimensional steady state hydraulic model for river channels, which allows for modeling of hydraulic structures, varying channel geometry, and estimation of hydraulic grade lines. The latest versions of HEC-RAS also have the capability to model one dimensional unsteady flow and sediment transport.

- **MIKE 11 and MIKE FLOOD** (Danish Hydraulic Institute (DHI)): These allow intensive modeling of flood wave routing, sediment transport, hydraulic structures, and overland/floodplain flow with 2-D flow fields.
- **River2D** (University of Alberta, Edmonton): River2D is a two dimensional depth averaged finite element hydrodynamic model.
- **RiverFLO-2D** (FLO-2D): RiverFLO-2D is a hydrodynamic, mobile bed model for rivers. It is a finite element flood routing model for high resolution river/flood plain hydraulics. RiverFLO-2D can route a large flood to the project river reach, and then predict the detailed 2-D channel hydraulics and overbank flooding through the shorter project reach.
- **HY7 WSPRO** (Federal Highways and Waterways Administration (FHWA)): WSPRO is a water surface profile computation model that can be used to analyze one-dimensional, gradually-varied, steady flow in open channels. WSPRO can also be used to analyze flow through bridges and culverts, embankment overflow, and scour at bridges. This model is similar in capabilities to HEC-RAS.
- **BRI-STARS** (BRIdge Stream Tube model for Alluvial River Simulation) (FHWA): BRI-STARS is a generalized semi-two-dimensional water and sediment-routing computer model that includes an integrated graphical interface. The model can be used to solve complicated river engineering problems with limited data and resources and is capable of computing alluvial scour/deposition for subcritical, supercritical, or a combination of water surface profiles that pass through critical depth.

Most of the packages listed above are intended to model complicated flow fields for purposes of estimating bridge scour, sediment transport, flood wave routing or flood plain analysis. These capabilities exceed that required to estimate the HGL between the Zosel Dam and Osoyoos Lake under defined flow and boundary conditions. Consequently, these models also require more extensive data sets, technical training and are more challenging to calibrate to ensure reliable results. In the case of commercial packages, the purchase or lease price is usually in the tens of thousands of dollars.

In our assessment, HEC-RAS is an appropriate model to employ to estimate HGLs on the Okanogan River. As with all models, the results are dependent on appropriate configuration of the model, adequate data and calibration of critical parameters.

Table 4. Evaluation matrix of a selection of hydraulic models available to estimate hydraulic grade lines (HGLs) on the Okanogan River.

Model	Relative cost	Labour requirements	Data requirement	Practicality for this application	Accuracy	Risk of non-detection of capacity deficiency[1]
HEC-RAS[2]	Zero (Freeware)	Low	Low	High	High	Low
MIKE 11 / MIKE FLOOD	High	High	High	Low	High	Low
River2D	Zero (Freeware)	High	High	Low	High	Low
RiverFLO-2D	High	High	High	Low	High	Low
HY7 WSPRO	Zero (Freeware)	Low	Low	High	High	Low
BRI-STARS	Zero (Freeware)	Moderate	High	Moderate	High	Low

1. Assumes models are properly configured and operated.
2. Model currently used.

4.3 SUPPLEMENTARY (REAL-TIME) MONITORING

The current monitoring system involves a post-hoc analysis of data – either directly using hydrometric data or indirectly using hydraulic modeling based on characterizing sections of the river channel. The current system however does not have the ability to detect the occurrence of an event that could pose a risk to channel capacity. As a result, there could be a considerable period during which the capacity of the river is potentially reduced during which channel improvements could be completed to reduce the risk of contravening Condition 3 of the Orders of Approval of 1985. Such real-time monitoring is not considered a replacement to current practices but as a potential supplement.

Tonasket Creek presents the highest sediment source risk to the Okanogan River upstream of Zosel Dam. Real-time monitoring of processes in the Tonasket Creek watershed could provide an indication or “red-flag” when technicians should investigate the potential for reduced river capacity near the mouth of the creek. Monitoring could be done in a number of ways:

1 **Monitoring severe rainstorm events** in the Tonasket Creek watershed. Rainfall magnitude and intensity could be monitored using telemetry and a relatively inexpensive weather station established in the watershed. A possible but less desirable option is to use existing weather stations in the region operated by the National Weather Service or Environment Canada. However, as the distance between the weather station and Tonasket Creek increases the station becomes less representative of actual conditions in the watershed. Review of weather (Doppler) radar records collected by the federal weather agencies may be an alternative worth investigating. Regardless, a rainfall volume/intensity threshold would need to be identified above which Tonasket Creek streamflows capable of bedload transport would likely occur. When the rainfall threshold is exceeded, this would trigger a technician to investigate conditions near the mouth of the creek or call a resident along the creek for an update of stream conditions.

2 a) **Monitoring high streamflows** in Tonasket Creek. Unfortunately the USGS hydrometric station Tonasket Creek at Oroville (#12439300) was discontinued in 1991. The re-establishment of a hydrometric station on Tonasket Creek with telemetry would provide a means to identify when flows capable of transporting bedload occur (i.e. a flow threshold). Ideally, the gauge would be located in a secure location along the lower reaches of the creek, however it is acknowledged that a stable location on lower Tonasket Creek may be challenging to identify. When the flow threshold is exceeded, this would trigger a technician to investigate conditions near the mouth of the creek, or make a phone call to a resident along the creek for an update of stream conditions.

b) An alternative to instrumentation would be to establish lines of **communication with local residents** living near the creek. A call would be made to the Department of Ecology (or other local representative) in the event that a large flow occurs in Tonasket Creek.

3 **Monitoring sediment transport** along the lower reach of Tonasket Creek. Bedload sediment transport in Tonasket Creek could be monitored by installing sediment traps in Tonasket Creek along with a mechanism that would trigger communication via telemetry in the event some threshold volume or mass of sediment is accumulated. Suspended sediment could also be monitored using a turbidity sensor however there are considerable technical difficulties to deploying such equipment in Tonasket Creek.

4 **Direct observation** of sediment transport along Tonasket Creek and sedimentation in Okanogan River. In the presence or absence of the instrumentation noted above, direct observations of conditions during high flow events on Tonasket Creek by an

experienced technician could prove valuable in reducing the time in identifying a channel capacity reduction. To facilitate this method and provide reference, key locations of the Okanogan River and lower portion of Tonasket Creek could be photographically documented on at least an annual basis during times with appropriate (i.e. low) river levels.

Albeit lower, there remains some risk of sedimentation near the outlet of Osoyoos Lake. Practical real-time monitoring at this location could involve:

1. Establishing lines of **communication with local residents** and State Park staff who frequent the area. A call would be made to the Department of Ecology in the event that a severe wind storm and/or shoreline erosion is noted along Osoyoos Lake.

Direct observation of the shoreline near the outlet to identify any evidence of shoreline erosion and more importantly sedimentation has occurred following a severe windstorm or event causing shoreline erosion. To facilitate this method and provide reference, key locations along the shoreline and near the lake outlet could be photographically documented on at least an annual basis during times with appropriate (i.e. low) lake levels.

Another near real-time monitoring method that is used to suggest a change in channel morphology is a shift in the (stage vs. discharge) rating curve at a hydrometric station. However, in this case, there is no existing hydrometric station in the *immediate* vicinity where sedimentation is likely to occur (i.e. near mouth of Tonasket Creek). Furthermore, given the regulated flow conditions, detecting shifts in the rating curve would be extremely challenging. Therefore this method is not considered viable.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY OF PRESENT CHANNEL MONITORING SYSTEM

In summary, the system used to currently monitor the flow capacity of the Okanogan River upstream of the Zosel Dam involves three (3) main components:

1. Post-hoc analysis of hydrometric records of Okanogan River and Osoyoos Lake to confirm that the river channel has the capacity to convey 2,500 ft^3/s while Osoyoos

Lake is at a level of 913 ft or lower. Flows and water levels sufficient to confirm this have been possible in only eight (8) of the last 22 years;

2. The river channel geometry is characterized by surveying four (4) established cross-sections in two general areas (near the outlet of Osoyoos Lake and near the mouth of Tonasket Creek) at 10–year intervals, or if five (5) consecutive years pass without river flows sufficient to confirm channel capacity using the hydrometric record; and

3. HEC-RAS modeling is performed by resurveying the four (4) control sections, and hydraulic grade lines (HGLs) are assessed to confirm that overbank flooding does not occur at discharges of 2,500 ft^3/s or lower.

5.2 HYDROMETRIC RECORDS

The first part of the monitoring system is a direct indication of channel capacity, and although it often cannot be used when flows are relatively low, it is a useful, practical and cost effective component of the system. **<u>It therefore is recommended that analysis of the hydrometric record continue as one part of the monitoring system.</u>**

5.3 CHANNEL GEOMETRY

The second part of the monitoring system involves the characterization of the Okanogan River upstream of Zosel Dam in two (2) general areas where sedimentation has occurred historically. The methods used involve a relatively simple and cost effective rod and level survey of four (4) cross-sections. The method has worked reasonably well from the Department of Ecology's perspective (Newkirk, pers. comm., 2009). However, using this method there remains some risk that sedimentation could go undetected either on the cross-section, within the general areas of the cross-sections, or in areas not being surveyed.

Currently, the survey resolution along each of the control sections is determined by the surveyors in the field. This complicates year-to-year comparisons of the survey data since it is difficult to determine if a measured change in the section is real or a consequence of different survey intensity from one year to the next. **In order to minimize this complication, it is recommended that consistent survey intensities be established at all four (4) control sections. Furthermore, it is recommended that for quality assurance purposes that the survey data be reduced immediately in the field and compared to previous survey data to confirm that any discrepancy along the section is real and not due to measurement error.**

It is acknowledged that areas not being surveyed are generally less likely to be subject to sedimentation given the channel characteristics and the location of known sediment sources. However, the existing survey method does not account for the possibility that sedimentation could occur in areas other than those currently being surveyed and is therefore not the most risk averse approach. **In order to minimize the risk of not detecting a change in channel morphology or sedimentation, it is recommended that the current survey method remain in effect, but that it is supplemented by a comprehensive survey between the outlet of Osoyoos Lake and Zosel Dam.** The objective of such a survey would be to establish the current channel geometry and confirm whether reliance on the four selected control sections as indicators of potential conveyance limitations is reasonable. Assuming that conditions have not changed significantly, a survey interval of 20 years is likely appropriate.

Two feasible methods for the comprehensive survey include:

- Surveying all the pre-1988 cross-sections between the outlet of Osoyoos Lake and Zosel Dam (refer to Acres 1986), using rod and level techniques or preferably total station surveying. Such a survey should include sufficient detail along the channel thalweg to identify any sills or high points; or
- Conducting bathymetric mapping using a boat-mounted sounder with survey-grade GPS. This method could provide a high level of information at a comparable cost to traditional surveying and likely in less time. It may be more cost effective to rent the

equipment or contract these services to the USGS or a private hydrographic firm, if possible.

5.4 HYDRAULIC MODELING

HEC-RAS modeling is the third component of the present monitoring system. It is our conclusion that HEC-RAS is a satisfactory model to employ for the purpose of estimating channel capacity under constraints identified by the IJC Order of Approval for the dam. There is no significant advantage offered by other software packages in this application. However, in order to ensure a high level of confidence in using the HEC-RAS model to assess adequacy of channel capacity, the following actions are recommended:

- **Calibration of the hydraulic model to HGL data surveyed during a significant flow event [exceeding 2,000 ft^3/s (57 m^3/s)];**
- **Periodic (every two years) field review to assess potential vegetation encroachment on the channel. An ongoing photo record of key channel features and locations should be developed and compared over time to identify changes in the river channel; and**
- **Review available aerial photography of the channel and compare to new aerial photography as it becomes available (assumed to be on a time interval of approximately five years). Aerial photos allow progressive changes in channel conditions to be tracked, particularly bars and vegetation.**

5.5 SUPPLEMENTARY ACTIONS

The current monitoring system does not have a means to detect when an event that poses a risk to the flow capacity of the Okanogan River occurs. Several possible methods described herein could be used as a "red-flag" to trigger when additional investigation by a local technician is warranted. However there are several technical challenges that are anticipated with these methods and most would not be practical or cost effective. **At a minimum, it is recommended that the WSDOE develop lines of communication with local residents that border Tonasket Creek and outlet of Osoyoos Lake or persons that frequent these**

areas. These persons would be requested to contact a representative of the WSDOE in the event a flow/water level threshold is exceeded in the creek. **Alternatively, local technician(s) contracted by the WSDOE should make regular observations of the outlet of Osoyoos Lake, Tonasket Creek, and along key locations of Okanogan River to identify whether there is a risk of reductions in channel capacity during high flow events or other periods of increased sedimentation risk. In order to provide a reference, it is recommended that key locations be identified from which a photographic record could be established.**

6.0 CLOSURE

Based on the findings of Part 1 of this assignment and recommendations noted herein, we recommend continuing with Part 2 but under a modified work plan. The original work plan involved further detailed investigation of alternative methods. In our opinion, sufficient investigation has been conducted on optional methods so that efforts can now be focused on developing the updated program consistent with the recommendations above.

We recommend that the Part 2 program consist of:

- Working with the WSDOE to discuss these potential modifications to the current monitoring program; and
- Developing a detailed description of the updated program along with equipment and labour requirements, as well as anticipated costs.

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Appendix A

Existing channel capacity monitoring rules (IOLBC, 1999b)

International Joint Commission
International Osoyoos Lake Board of Control
1201 Pacific Avenue, Suite 600
Tacoma, Washington 98402
(253) 428-3600 • FAX (253) 428-3614
http://wa.water.usgs.gov/IJC/osoy.homepage.html

October 7, 1999

Mr. Keith E. Phillips
Manager, Water Resources Program
State of Washington
Department of Ecology
P.O. Box 47600
Olympia, Washington 98504

Dear Mr. Phillips:

Condition 4 of the IJC Order of Approval (December 9, 1982) and subsequently revised by the Supplementary Order of Approval (October 17, 1985) calls for the applicant (State of Washington Department of Ecology) to "...take all measures to ensure that the flow capacity of the Okanogan River, upstream and downstream from the control structure, enables the control structure to pass at least 2,500 cubic feet per second when the elevation of Osoyoos Lake is 913.0 feet USCGS and there is no appreciable backwater effect from the Similkameen River."

In accordance with your "Zosel Dam Operating Procedures Manual", July 1990, the Department of Ecology (Ecology) established four control cross sections for monitoring the dredged areas of the Okanogan River channel below the outlet of Osoyoos Lake (pp 48-55). Prior to 1996, Ecology resurveyed these cross sections annually to detect buildup of sediment and possible loss of channel conveyance. The annual surveys have shown no appreciable changes. In addition, hydrologic records published by the U.S. Geological Survey have confirmed that the Okanogan River channel exceeds the requirement mandated in Condition 4.

On September 24, 1996, Mr. Ray Newkirk of your office petitioned the International Osoyoos Lake Board of Control (IOLBOC) to use hydrologic records, as published annually by the U.S. Geological Survey, to verify the hydraulic capacity of the outlet channel from Osoyoos Lake. Permission was granted for that year. During its meeting of September 16, 1998, the IOLBOC approved the following alternative procedures to annual surveys:

1) Hydrologic records of Osoyoos Lake level and Okanogan River at Oroville discharge can be used in lieu of control section surveys to verify that the channel's capacity exceeds the requirements of Condition 4 of the Orders of Approval. These records should be cited in Ecology's annual report to the IOLBOC.

2) If the hydrologic conditions that could verify the channel's capacity do not occur for a period of 5 consecutive years, then control section resurveys must be done prior to the 6th year after the last successful verification.

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3) The control section cross sections shall be resurveyed at least every 10 years, commencing in September 1996, regardless of verification of channel capacity through use of hydrologic records.

4) The IOLBOC reserves the right to request a resurvey at any time if there is reason to believe that a change has taken place to decrease the conveyance of the outlet channel. Examples include evidence that the Tonasket Creek delta has encroached into the main channel, or that hydrologic records indicate channel capacity is decreasing.

5) A HEC-2 or equivalent step-backwater hydraulic analysis shall be made as a follow up action whenever a resurvey of the channel cross-sections is done.

These alternative procedures were discussed with Mr. Newkirk prior to the Board's Public Meeting on September 16, 1998.

The IOLBOC requests that you incorporate these alternative procedures into the Zosel Dam Operating Procedures Manual, and at the same time to update the information contained in Chapter II, Communications Directory and Chapter IV, Data Recording and Reporting, and provide the Board with an updated copy of these sections.

Finally, the Board is concerned that the relaxation of annual survey requirements effected by the above-mentioned alternative channel capacity verification procedures may result in loss of monumentation of control cross sections. We request that the location of the control cross sections be marked by a surface monument and a re-bar be driven to ground surface height to assure that horizontal control is preserved. The Board further requests that the locations of the monuments be documented by either GPS technology or traditional ground surveying methods.

Please direct any questions you have on the alternative procedures to Ray Smith, Acting U.S. Section Secretary, IOLBOC (509-353-2633). We appreciate your continued cooperation in the management of Osoyoos Lake water levels in accordance with the IJC Orders of Approval.

Sincerely yours,

Garald G. Parker, Jr.
Acting Chairman International Osoyoos Lake
Board of Control

cc: Chairman, Canadian Section, IOLBOC
Members and Acting Secretary, U.S. Section, IOLBOC
Secretary, U.S. Section, International Joint Commission